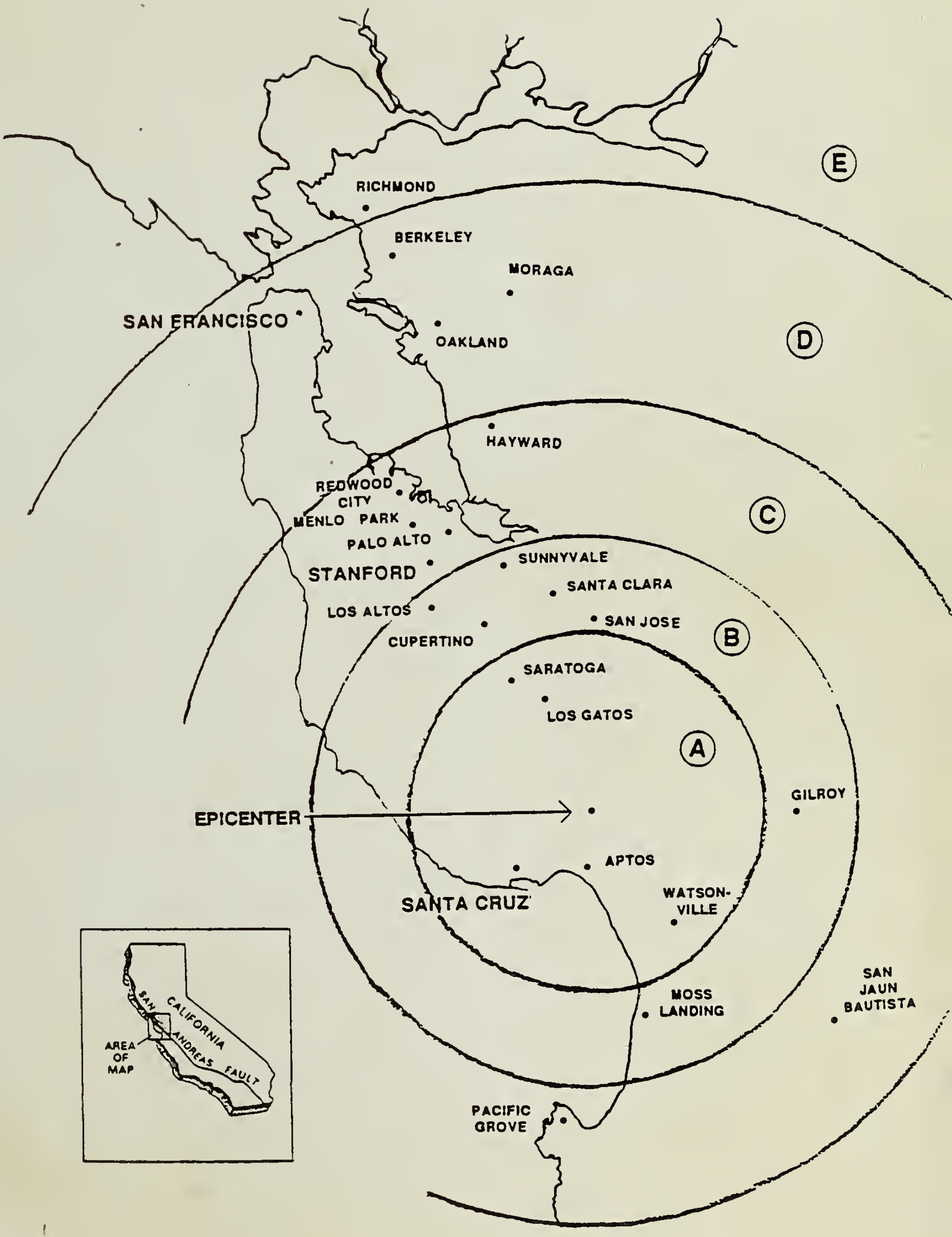
Library Buildings and the Loma Prieta Earthquake Experience of October 1989

David C. Weber



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LIBRARY BUILDINGS AND THE LOMA PRIETA EARTHQUAKE EXPERIENCE OF OCTOBER 1989

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Library Buildings and the Loma Prieta Earthquake Experience of October 1989

By David C. Weber

California State Library Foundation
Sacramento
1990

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As a friend wrote me last fall: "In an area that is visited from time to time by devastating earthquakes, a Library Director's calling must be viewed as a truly hazardous one. The work of years can be sorely damaged in a few seconds of seismic disturbance. But there can be no speedy restoration. Creating a great research library resembles the accretion of a coral reef rather than the stocking of a supermarket or a department store. And some library items that had been destroyed may be irreplaceable."

Anyone who has lived through a "major" earthquake of Richter magnitude 6.5 or larger (8.0 and above is considered "great") and anyone who has had to cope with the library results of a major earthquake can be sympathetic with others of a similar experience. My deepest sympathy goes to anyone who has now or will in the future be responsible for a research library that has suffered in a major earthquake.

David C. Weber
Ida M. Green Director of
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Prior Steps Taken to Prepare For a Major Tremor

There is no library in any of the coastal area of California that will not have taken a number of steps to prepare the building and collections as well as the staff for a "big one." For one thing, the State of California has responded to damage suffered in California earthquakes of 1927, 1933, 1971 and 1978 by requiring most buildings to withstand a horizontal force equal to at least two percent of the force of gravity, to conform to tighter design requirements for steel and concrete frames, to meet additional guidelines for irregularly shaped structures, and to meet requirements where soft and hard soils require more building resistance to horizontal forces than those on rock. Additional requirements were introduced for buildings on soft clay and bay mud after the 1985 earthquake in Mexico City, in which intensity of ground shaking reached Modified Mercalli IX and X in Mexico City, 350 km (217 miles) away from the epicenter.

Typical of many institutions and cities and corporations, Stanford University had a 15-year program of seismic bracing and regular earthquake preparedness drills. It had conducted a comprehensive survey of all campus buildings built prior to 1934 to assess earthquake risk. Priorities were established a few years ago for fifty unreinforced masonry buildings (sandstone and brick) and eighteen concrete or steel frame buildings with concrete, brick or tile walls. The number of people expected to be in a particular building was multiplied by the number of hours per day the building usually was in use; and, when combined with the physical conditions of the building, the overall risk of each building was determined. Priority for strengthening was then assigned.

The Stanford main library (the Cecil H. Green Library) is located on an alluvial plain, 8 km (five miles) from San Francisco Bay. The very thick alluvium is composed of interbedded, fine silty sands, sandy silts and coarse sands with gravel which contain pebbles, cobbles and boulders of various rock types. These soils are generally firm with moisture contents ranging from 9 to 30 percent but no free water above 21 meters (70 feet).

The original 1919 wing of this library has a steel frame with concrete floors and solid tile walls. The complete steel frame is highly redundant and offers substantial strength to resist earthquakes, but the infill walls were vulnerable in a major tremor. The University determined to upgrade that structure and various other old buildings rather than to fully reconstruct just a few buildings with the worst conditions. This was a shift from the strategy followed during the 1950's into the 1980's of fully reconstructing the larger unreinforced masonry buildings.

Just last September, a month before the earthquake, the University updated its seismic risk program in response to a recent State of California regulation concerning risk mitigation of unreinforced masonry buildings. In the seismically active zone in which Stanford lies, California Senate Bill 547 requires every local jurisdiction to mitigate the seismic hazards of unreinforced masonry (URM) buildings. The County of Santa Clara intended to pass an ordinance requiring compliance by the University with the State law. In addition to forty-four URM buildings pertaining to State Senate Bill 547, Stanford has ten buildings that represent comparable risk. Depending on the earthquake standards used for strengthening, between $50,000,000 and $80,000,000 could be needed, whereas the University last fall was budgeting $800,000 per year for upgrading all the inventory of potentially hazardous buildings.

The Stanford Library had conducted a Library building safety hazard survey over the past dozen years. Actions were taken to eliminate most threatening equipment conditions and to safeguard chemicals. Nearly all stacks were bolted to the floor and to the walls as was deemed necessary. Library staff emergency manuals of procedures were placed in all units, most of which had first aid kits and flashlights. Library managers had been informed by university officials that we should plan on no university help immediately after a campus disaster, no help with utilities, property rescue or safety precautions. Most gratifying was the fact that, just months before October 1989, a structural rebuilding of a seven level stack that housed over 700,000 volumes had been completed - in the original Green Library book stack which engineers had stated throughout the 1960's and 1970's to be extremely vulnerable if there were a major earthquake.

The Events of October 17, 1989

On Tuesday afternoon at 17:04, the most severe earthquake in the Bay Area since 1906 occurred, lasting 15 seconds with a magnitude of Richter 7.1. The Loma Prieta epicenter was some 13 km (8 miles) inland from the ocean, east-northeast of the coastal city of Santa Cruz, in Nisene Marks State Park on the southern slope of the Santa Cruz Mountains under which runs the 1,130 km (700 mile) long San Andreas geologic crustal fault. The main rupture was at a depth of about 18 km (11 miles) beneath the earth's surface and extended about 40 km (25 miles) northwest and southeast and upward about 13 km (8 miles), stopping about 5-6 km (3 to 4 miles) below the surface. The Pacific Plate next to the ocean moved about 1.9 m (6.2 feet) northwest along the North American Plate and moved upwards 1.2 m (4 feet), though the surface displacement was 18 cm (7 inches) horizontally and 36 cm (14 inches) vertically. The tremor was felt over an area from Los Angeles on the south to the Oregon state line on the north and to western Nevada on the east, as much as 560 km distant. Called the Loma Prieta Earthquake, it resulted in 62 known deaths, at least 3,700 injuries and more than 12,000 people homeless. At 1157 m (3,800 feet), Loma Prieta, very near the hypocenter, is the highest point in the Santa Cruz Mountains.

The Loma Prieta earthquake was exceptional because of the extent of vertical shift, the underground depth of the epicenter and the numerous ground cracks but no recognizable primary surface faulting. Amplified ground motion in unconsolidated sand and mud contributed to heavy building damage in one district in San Francisco and failure of a major double-level automobile freeway in Oakland. There were no known short-term seismic or strain precursors to warn of the impending earthquake. The seismic shaking triggered thousands of landslides in the areas of steep unstable slopes, including many man-made cuts and fills. Some of the ground cracks extended 50 km (30 miles) northwest of the epicenter to the edge of Stanford University's undeveloped back-campus property.

On the Modified Mercalli Intensity Scale of ground shaking, the region surrounding Stanford University experienced intensity VII. This intensity frightens everyone, standing is difficult for people, damage is negligible in buildings of good design and construction but considerable in badly designed or poorly built buildings, hanging objects quiver, furniture and weak chimneys are broken, loose bricks and tiles fall. A Modified Mercalli IX-X results in major damage; XI-XII total or nearly total damage.

At Stanford, there was no sharp jolt as in some temblors but rather a major visible rolling motion. People had a hard time standing in some buildings. They heard a roar and loud crashing, particularly of falling furniture and in some places of breaking dishes and glass. There was an immense amount of dust. (Indeed, fishermen off the coast of Santa Cruz spoke of seeing a huge cloud of dust rising from the entire land mass.) Oak trees suddenly discharged their full load of acorns. Tall palm trees were shaking like giant dustmops. Swimming pools produced a seiche, sloshing as much as 3 m (10 foot) high waves outside the pools. Typical of many a family, parents in a campus home rushed to get out of their house, gathering their baby and calling their 6-year old son to follow. When they realized that the son was not with them, they frantically searched and found him standing in the garage with every loose item in a pile around him. As they breathed a sigh of relief, he looked up in apprehension and claimed "I didn't do it."

For the next three days, the University was only partially operational. Most libraries were closed one or two days. Teams of engineers and other qualified personnel reviewed every building on campus and classified them according to damage. Thus, the older 1919 wing of Green Library building was closed to staff and classified as having major damage with exterior cracks, broken stucco, many dozen broken windows, interior walls severely damaged and asbestos conditions suspect. The 1980 wing had very light damage: a few ceiling grills and light fixtures dropped. The two wings of this main library had audibly pounded against each other. The Meyer Memorial Library (the instructional and media library building built in 1966) had light damage with a few windows broken, ceiling tiles loosened, light lenses hanging and a pedestrian bridge at one end of the building pulled apart from the main building by less than 2 cm. Electric power was out in some places for a day or more;fire alarms had gone on in the Green Library because of dust and in the Business Library because of the drop in water pressure. Throughout the campus,. the repair cost is about four percent of the replacement value of Stanford's total physical plant.

Nobody was severely injured on the Stanford University campus. One student from Indonesia had immediately gotten out of his study desk in the Food Research Institute Library just as the bookstacks came down and buried the desk. Another student had just stepped out of his car not far from the Chemistry Library when part of the stone chimney demolished his car parked by the building. A student rushing to leave the Law Library struck his head. And at the Linear Accelerator Center, a technician suspended in a bucket from the massive overhead crane in the Collider Experimental Hall swung precariously to and fro above the gaping pit as the crane jostled back and forth in its tracks.

Fortunately the earthquake occurred an hour before sunset so there was some daylight for immediate actions. Also, fortunately, use of the libraries was exceptionally light, in part because a World Series championship baseball game was just starting thirty miles away and broadcast on TV and radio.

The most obvious result in the Stanford libraries was the 750,000 volumes spilled onto the floor. In general, a greater percentage of books fell on each higher floor. Staff who were able to get to campus were asked to return Thursday noon to begin re-shelving the collections in the main library where about twenty percent of the books were shaken off the shelves. In the Engineering Library, half of the books were on the floor. In the Mathematics and Computer Science Library nearly all the books were off the shelves. Nearly a quarter fell in the Law Library and nearly ninety-five percent in the Business Library. On the other hand, there were relatively few that came off in the Swain Chemistry and Chemical Engineering Library, Music Library, Art Library, Physics Library and the Lane Medical Library. At least ten percent of the bookstacks in the Earth Science Library had racked, leaning from an outside wall across an inside aisle. In the Food Research Library basement level, at least half of the ranges had fallen sidewise or endwise. No material fell from any compact shelving installation on movable carriages over a raised safety floor. It is estimated that 650,000 volumes were reshelved over the next few days, though shelf reading required attention for the next five months.

Metal book shelving failed in five locations. In the Medical Library, a dozen free-standing metal double-face ranges leaned thirty degrees toward the end panel. Although the books and overhead bracings kept the ranges from total collapse, almost all cross bracing by tie rods with turnbuckles within a section of shelving failed since either the ends of the braces unhooked or the hook pulled open or the metal slot was ripped out by the hook. Where shelving was against the wall, the maximum problem was shelving being five cm (2 inches) out of plumb.

Where shelves were more rigid, more books fell. In the Crown Law Library, twenty-two basement ranges went down in domino fashion because they had top bracing (strut or hat channel bracing) which ripped right out of the wall. Shelving on upper floors was not thoroughly braced but it all rode out the tremor after pitching nearly a quarter of the volumes to the floor.

The main building of the Graduate School of Business is a 1967 structure in which the library has parts of four floors. The entire building is cantilevered reinforced concrete. Most of the shear walls failed but did not collapse. Most of the steel shelves buckled. Much of the suspended ceiling broke loose dropping the suspended lighting. A 6.41 cm (2 1/2 inch) hot water pipe broke on the third floor. Throughout the night under emergency lights, the Dean for Administration, the Dean for Academic Affairs and the Library Director fished books out of the water amidst collapsed shelves.

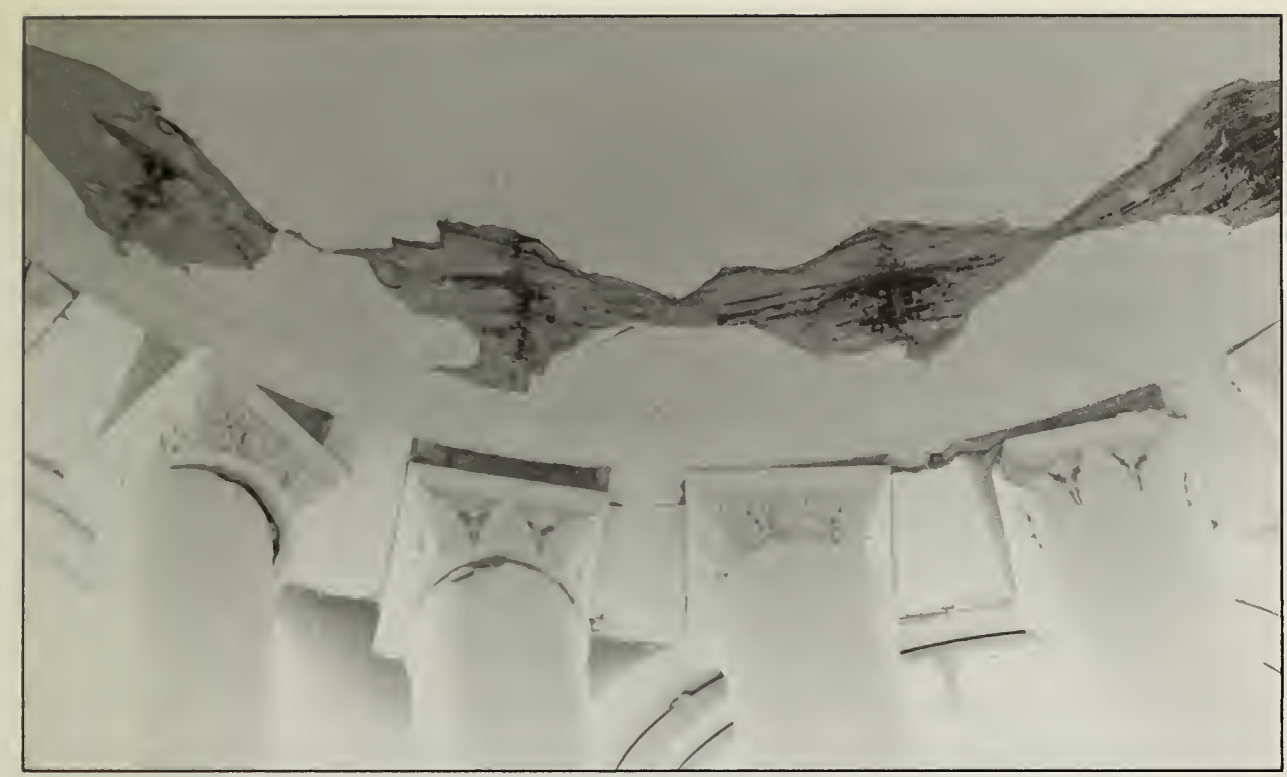
As for equipment, all file cabinets and eighty-five percent of the map cases in the Branner Earth Science Library had fallen, and a few of these metal sheet map cases were racked. The cabinets, made up of 5-drawer segments, typically had their drawers open up which, in turn, caused the whole unit to tip and slide off the unit or units below.

And a few metal four-drawer file cabinets and several tall metal microfiche cabinets in the Government Documents Library were ruined when drawers slid open, toppling the cases forward and severely distorting drawers and their slides beyond repair. The Law Library elevator was out of use for weeks when damaged as a counter weight fell in the shaft.

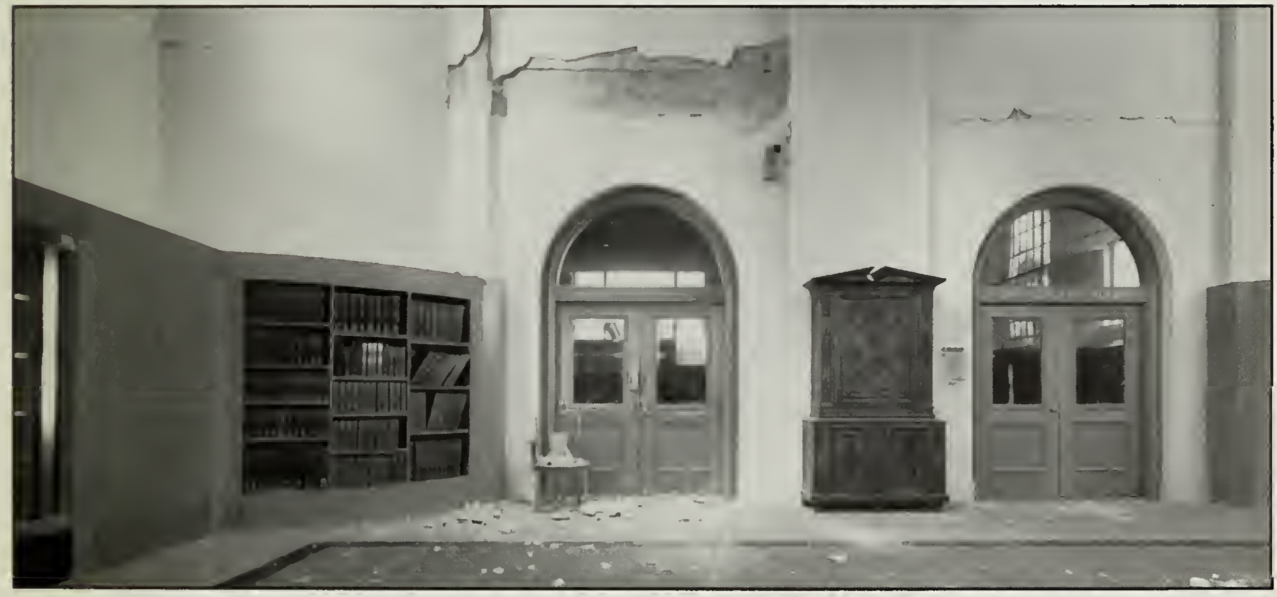
There were two library microcomputers damaged although a few others were soaked or fell, and all were checked to see that dust had not led to malfunctioning. The campus computer system was out for seven hours because of a power check on the central processing unit, corrected when a power converter was replaced. The situation in the computer room on a false floor was kept operational although many of the disk units moved as much as a foot or more from their original location, but remarkably enough none of the relocation of equipment caused any functional problems.

It was a pleasant surprise that, excluding the Business Library, only between 2,000 and 3,000 books had been physically damaged. However, the book repair cost may reach $100,000. Those were mostly bindings that had been broken as they fell to the floor or as other materials fell on top of them. This result is not surprising since in many range aisles the books were piled a meter (two and a half feet) high. Some water damage occurred in sheet map cases in the Earth Sciences as the result of a faucet having been turned on by a falling cabinet on the floor above the Library. Some trays of cards in the Hoover Institution East Asian Library were briefly wet when a pipe, that had perhaps been cracked in the earthquake, began gushing the next week. One book in a geologist's office was trapped in a floor when the wooden structure opened up momentarily and then closed to hold the book as in a vise. (The only persons known to have been crushed in a ground fissure are a field worker in June, 1948 during the earthquake in Fukui Prefecture and two children during the great Alaskan earthquake of 1964.)

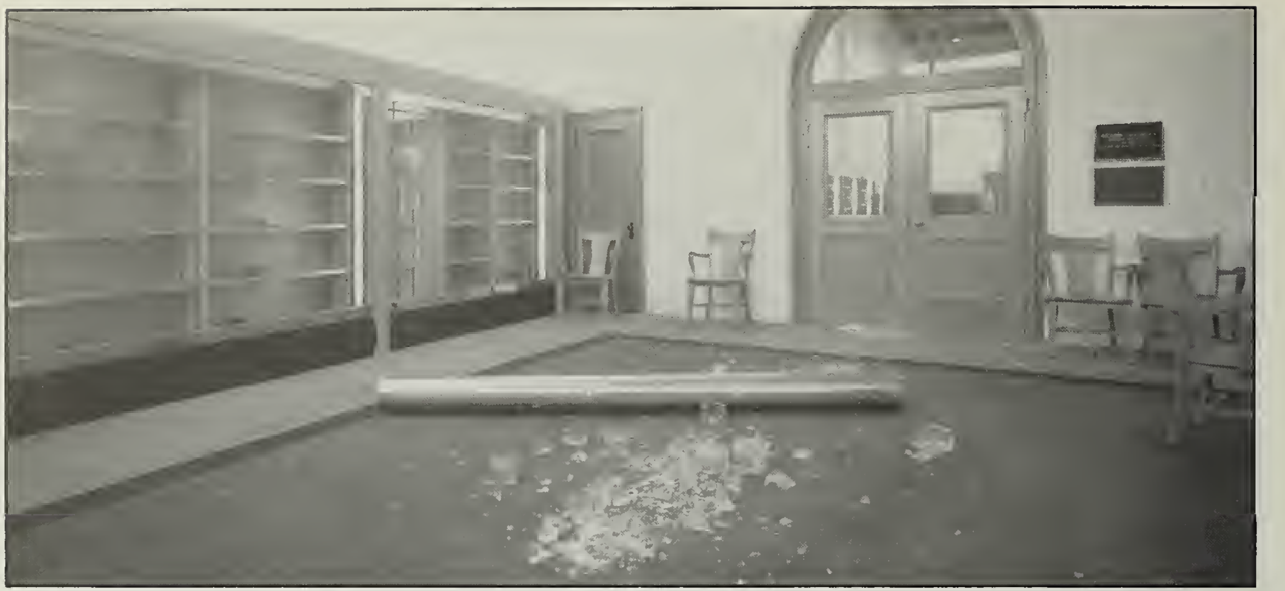
Engineers have stated that the relative brevity of the Loma Prieta temblor was beneficial. If the strong shaking had lasted two or three times longer, the damage would have greatly increased. The quake magnitude would have rapidly become much larger.



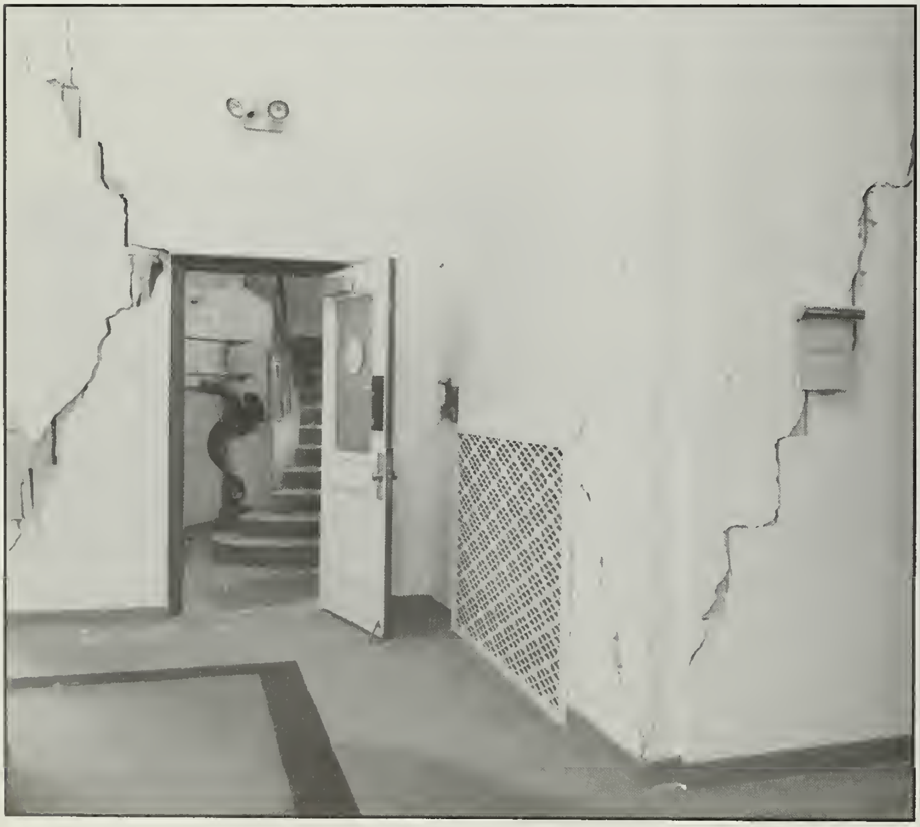
Severe seismic forces fractured the ceiling structure and shook out of alignment several non-load bearing columns. (Dome of the Louis R. Lurie Rotunda, Green Library, West Wing, Stanford University)



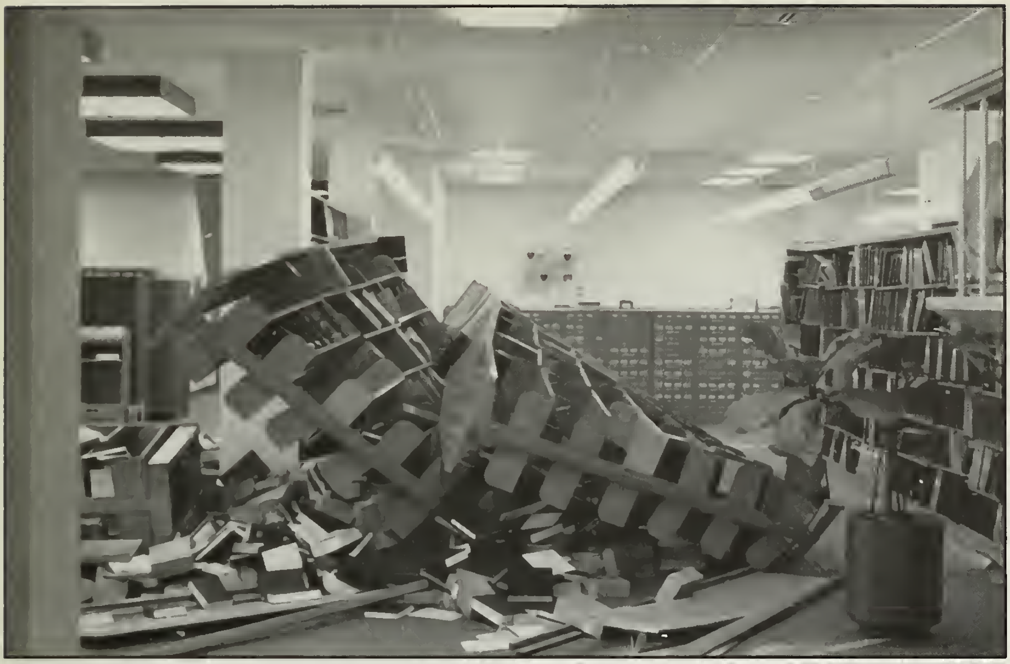
Chair broken by falling hollow clay tiles and heavy plaster. Pieces of the wall material fell during after-shocks for six months. (Charles and Frances Field Room in Special Collections, Second floor of the Green Library)



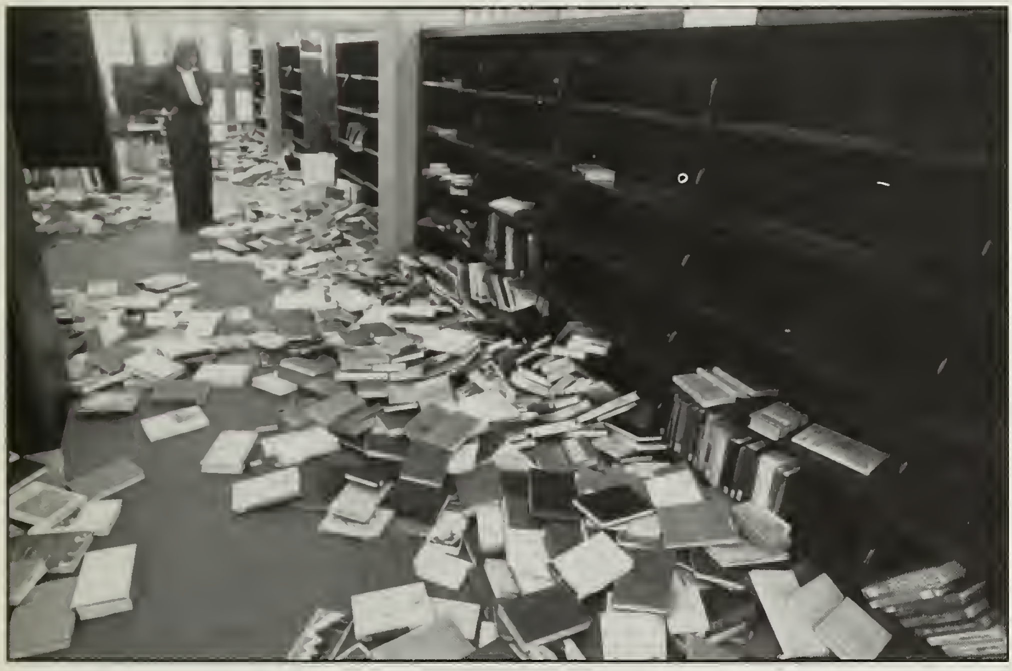
Very heavy light fixture which shattered as two wire hangers broke loose, just after a student class session ended. Fixture was new in 1982. (Samuel I. and Cecile M. Barchas Room, Second Floor, Green Library)



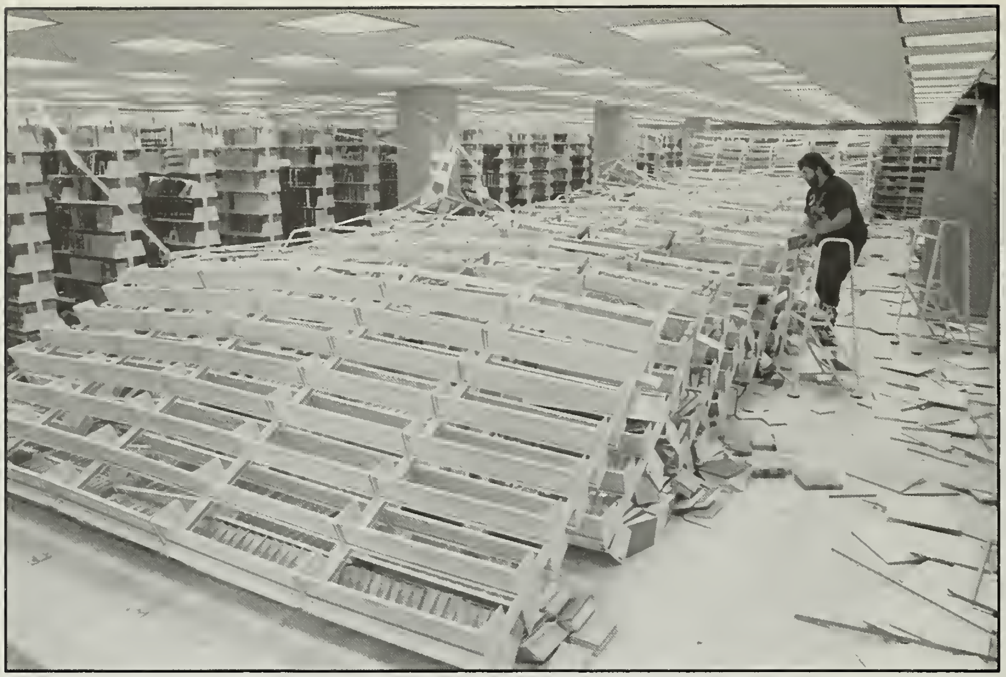
Interior in-fill walls severely fractured, hollow clay tile covered with plaster. Note grille-covered radiator which remained in place while its twin broke loose and collapsed. (Lurie Rotunda, Green Library)



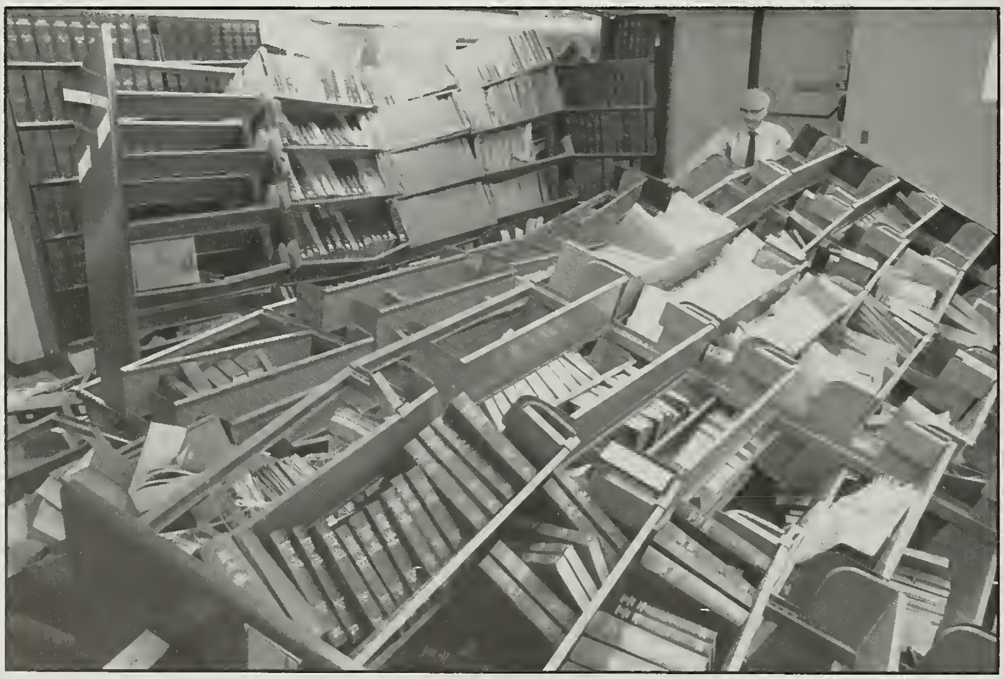
Inadequately braced shelving ranges which were able to be reerected and braced. A 1968 installation. (J. Hugh Jackson Library of Business, Stanford University)



Upper floor of the J. Henry Meyer Memorial Library showing book shelving intact but over 90 percent of the books disgorged. Building was opened in 1966. (Stanford University)



Fallen ranges of shelving braced inadequately in basement of the Crown Law Library. Building erected in 1975. (Stanford University)



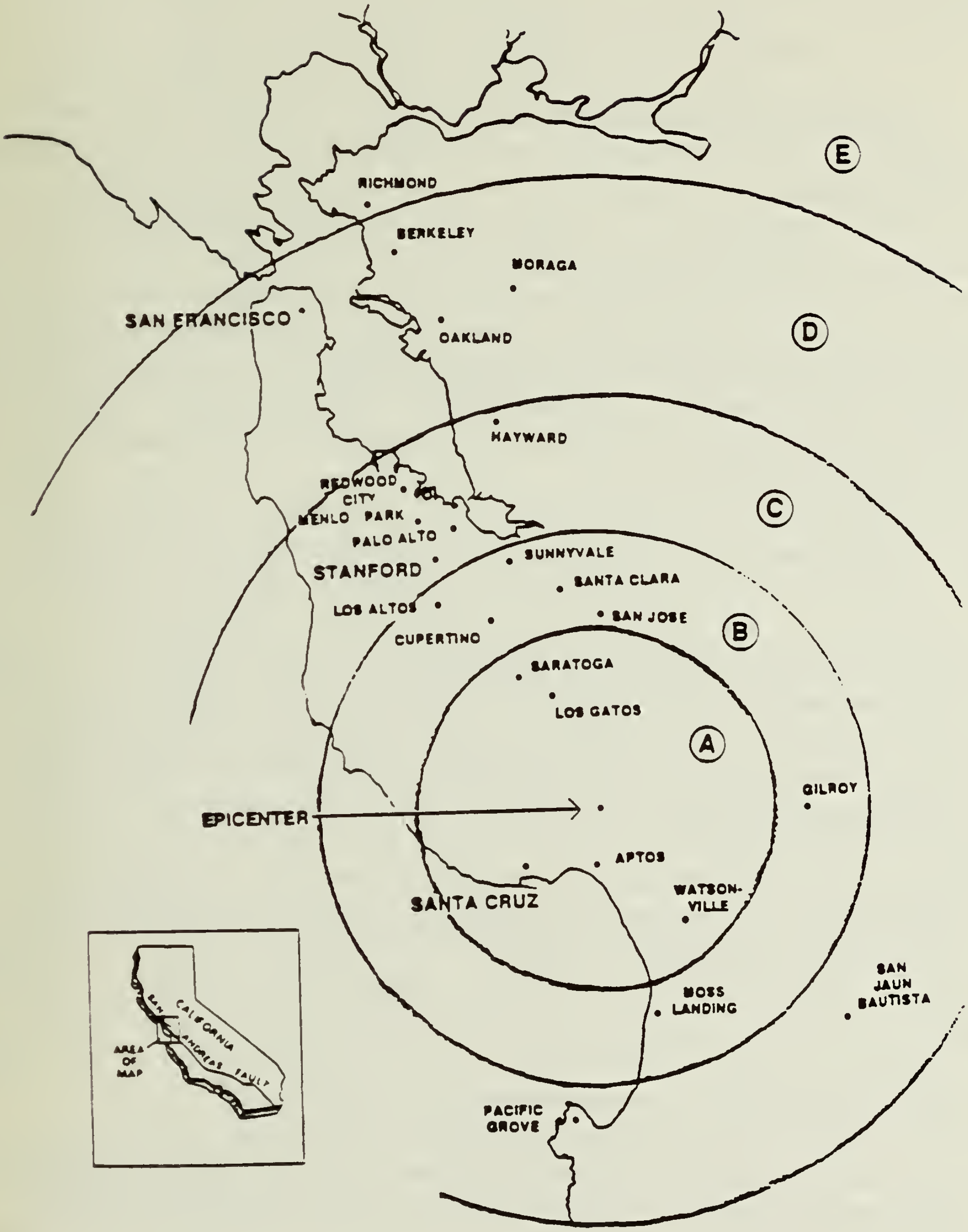
Problem faced by librarian with fallen, racked, and disformed shelving fully loaded with collections. (Food Research Institute Library basement, Stanford University)

Experience of Selected Libraries Within 120 km (76 miles) of the Epicenter

Reports from over forty libraries of different types document a wide variety of experiences. They are chosen as representative and include most of the more damaged instances. I am aware of no library where all the material was off the shelves, where all the shelves collapsed, or where any considerable percentage of the book materials were damaged. However, physical damage to libraries was widespread and extensive. Book shelving failed in many locations. Where library shelving failed, it evidently did so because of inadequate building structure or inadequate or no stack bracing against seismic forces. The shelving failed in some instances where the building itself was very flexible or structurally weak. The footings of the structure and the soil conditions on which the building was erected may have had a great deal to do with the shelving failures. Some old buildings held up very well. Some new buildings did not. Normal library services were curtailed for days and in some cases weeks and even many months. In two cases, the library buildings will never be opened again.

Since experience differed greatly among libraries, this summary of experience will be presented in five concentric geographic regions, as if they were the colored bands of an archery target with the epicenter the bulls-eye. Region A covers libraries that are within 30 km (about 20 miles) of the epicenter. Region B covers libraries that are 30-50 km (20 to 30 miles) distant. Region C covers those from 50-75 km (30-45 miles) distant. Region D covers libraries that are 75 to 110 km (45-70 miles) distant. And Region E covers one library further away. The libraries in this summary are representative of academic libraries, public libraries, governmental libraries, libraries of commercial firms, and a few book stores.

The libraries are distributed over a geologically complex region with three major geologic faults and at least four lesser faults, each of which roughly follows the coastline in a northwest to southeast direction. A few of these libraries are in relatively small communities along the ocean on the west side of the San Andreas fault on that part of the earth's crust which moved upward and northward. Most of the libraries here reported are in the densely settled San Francisco Bay region. One group is in the south end of the San Francisco Bay and across the steep Santa Cruz Mountains from the ocean. Another group is on the San Francisco Peninsula, the west side of the Bay, also separated from the ocean by the Santa Cruz Mountains. There are other major communities on the east side of the Bay, large cities that are near the ocean entrance to the Bay or on the east side of the Bay, and smaller communities that are on the north side of the Bay or east of the various low mountain ranges that separate the Bay area from the inner valley of California. (See the map showing the distribution of the library case studies among the five regions.)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GILROY
EPICENTER
APTOS
WATSON-VILLE
SANTA CRUZ
MOSS LANDING
SAN JAUN BAUTISTA
PACIFIC GROVE
CALIFORNIA
SAN ANDREAS FAULT
AREA OF MAP

Region A
(Libraries within 30 km of the epicenter)

Cabrillo College Library: In the town of Aptos just 10 km (6 miles) southwest from the epicenter, this 1960 building had no damage, although the entire campus was closed for eight days to check for structural problems and for asbestos testing. A third of the 70,000 volumes, magazines and microfilm ended up on the floor. Nearly all stacks run north and south. They all stood up although they had no cross sway braces within sections and no top bracing. Part of some east-west shelving against a wall pulled away from the wall and one of these sections tipped over. Microfilm boxes fell out of case drawers and the reels came out of the boxes, but no cases were damaged and no reading machine fell.

The Santa Cruz City-County Library System: The Central building is 15 km (10 miles) from the epicenter. The previous August there had been a 5.2 quake with a four-day governmental alert for major aftershocks. An Emergency Operations Center (EOC) was set up, procedures were reviewed and a list of required supplies was issued. Thus, on October 17th, every library flashlight had a charged battery, yet most branches had no battery-powered radio due to lack of funds. At one branch, the special wrench to turn off gas did not work. The main shock at 17:04 was followed by a 5.2 at 17:44 and forty-five other serious aftershocks on through the night as the EOC functioned from 17:35 with help of the library director. Electrical power in downtown Santa Cruz was out for forty-eight hours. Water mains were broken all over the county, so the library had no water for thirty-six hours. As the Director of Libraries has stated: "In the midst of a community-wide emergency, if you can't find a way to do it yourself, it isn't going to get done. None of the normal resources are available."

At least seventy-five percent of the collections in the Central Library and in each of nine branches had been thrown to the floor no matter in what direction the shelving ran, with audio-visual material suffering the same as books. The Central branch's second floor storage collection had metal bracing installed on the tops of the stack ranges, at right angles to the stacks, and affixed to the walls. In the shake, the bracing popped out of the walls, moved back and forth several times, and whip-lashed the stack ranges beneath them. The result was a twisted mass of steel shelving on the floor, not to mention 17,000 books and periodical backfiles. Shelving without the bracing swayed but stood. Although it is structurally unsound seismically, at least it could be temporarily braced.

From the Santa Cruz City-County comes possibly the most horrible library "where I was when the earthquake hit" story: The Garfield Park Branch Library Manager was at the dentist's having a root canal job done at 17:04 on October 17th. The dentist finished up by flashlight. She then spent two hours trying to get home via roads which had been closed by slides and the like. No pharmacy was open, so she couldn't get her pain reliever prescription filled. And when she finally did get to her house, she couldn't get in the door because the refrigerator had slid against it and blocked it. It is not recorded where she spent the night.

Bookstore of George Robert Kane (Santa Cruz): A quarter of the entire 16,000 volume antiquarian collection fell from the shelves. Interestingly, all books on the south walls were thrown to the back of the shelves. The shelving running north and south were the principal disasters. Almost all of the books in the shop had been wrapped in either mylar or acetate covers for protection, and the books seemed to have slid out en masse and there was no damage except for one fragile leather binding. In three other Santa Cruz stores of new books, the books were thrown about forcefully and walls collapsed. Where the plaster or other objects fell on the books, the books were damaged or ruined, but the great majority of the collections were saved in all cases.

Santa Cruz County Historical Trust: This non-profit group operates a museum and the historical archives. The collections of the Historical Trust were maintained in a handsome brick and sandstone building dating from the turn of the century. It was densely packed with shelves full of boxes and books, file cabinets, map cases and racks, in addition to space for registration and research work. When the earthquake hit, the collections manager was just closing up for the day. The entire building rocked violently and the lights went out. Hearing objects crashing and falling, she saw part of a brick wall give way, letting light into the room. Papers, objects, files, and books cascaded all over the floor near the exit door. When the initial shock subsided, she made her way to the door, locked it behind her and left with the other badly shaken occupants of the building. That was the last the archive collections manager would see of the archives for an entire month - until their removal was authorized. The building had suffered severe structural damage, and based on preliminary assessments the city officials deemed it unsafe for entry. The most pressing problems facing the city were rescue of victims, demolition of unsafe structures and removing contents from those buildings slated for demolition.

University of California at Santa Cruz (UCSC): Both the main McHenry Library and the Science Library buildings are less than twenty-five years old and there was no structural damage to either. About six percent (57,000 volumes) of the total book collection fell to the floor. In both buildings there was a much larger percentage of the collection spilled on the upper floors, decreasing in percentage toward the ground floor. On the fourth floor of the Science Library some forty percent were spilled. On the fourth floor of McHenry, the percentage was smaller overall, but was as much as fifty percent in some portions of that floor. The librarian indicates that the amounts would have been much higher had it not been for the directional orientation of the building shaking. One staff member whose desk is normally overrun with piles of paperwork joked that he really needed no time at all to put his office back in shape since it did not look much different after the quake than before!

Also at UCSC, there was a definite pattern to the failure of the stack shelving and the spilling. Though the epicenter was to the east, the library staff assert that the main direction of shaking was in the north-south direction. Thus shelving that runs east-west dumped a much higher percentage of books onto the floor, while shelving running north-south suffered a high degree of longitudinal failure of the sway bracing within the stack sections. The majority of the shelving on the upper two floors of the main library are aligned north-south. As a result, relatively little fell off of the shelves, while virtually all the stack ranges failed structurally due to inadequate attachment of the sway braces. The shelves collapsed to a point where the books were supporting the shelving. Bracing of shelving across the top of aisles, between ranges of shelving, held up well in both buildings. A librarian reports: "We found it interesting that the motion was so strongly north-south here. We are situated 6-7 miles (10 km) almost due west of the epicenter.... It seems that the ground motion here was pretty much parallel to the direction of movement along the fault, which trends from north-northwest to south-southeast along this portion. Had it been perpendicular, we would have been faced with much more of the collection having to be reshelved. Instead, we were able to right most of the failed stack ranges without unloading them."

At UCSC there was no damage to audio-visual material, perhaps because it was housed on the ground floor. Damage to the book collection was only a small fraction of a percent - perhaps 400 volumes needing repair or rebinding. All computer terminals came through entirely unscathed even though they were dispersed throughout the buildings. There were no problems with water or fire alarms, yet one of the laboratory buildings next to the Science Library had serious flooding. Electric power to the libraries was off for a day and a half.

Clearly, the main problem had been the inadequacy of the bracing to limit sway in the stacks. The braces were only 6.35 mm (1/4 inch) gauge and had flimsy hooks on the ends to attach them to slots in the uprights. Most of the hooks popped right out of the slots during the quake, rendering the bracing ineffectual. Many of the hooks were simply straightened out by the force. Since then the library has contracted to have all of the sway bracing upgraded with heavier gauge metal and with each brace being bolted to the shelving uprights, rather than hooked into slots. Another observation was that the shelving from different vendors had different rates of failure. UCSC had a few ranges of newly installed shelving that is of the welded-frame variety and it did not budge during the quake although it was installed running east-west and a few books did fall off.

Although nobody was injured during the earthquake, a woman had been trapped in the McHenry Library elevator for nearly an hour after the quake. She experienced several sizeable aftershocks before finally being brought out from the elevator cab. With remarkable composure, she said in a very matter of fact tone, "OK, I need a hug now."

Watsonville Public Library: Located just a short distance further from the epicenter than Santa Cruz, the downtown area of old weak buildings in this community suffered greatly. The public library director was another who spent weeks helping in the local EOC though sixty percent of the library books were thrown from shelving. The library building came through well, yet much of the suspended ceiling had to be replaced. Electric power was off for thirty-six hours because of drifting gas from city leaks. Almost two months later, the library was an island of tranquility in the midst of chaos as the "clam shell" tractor loaders went about the demolition of structurally failed buildings.

Town of Los Gatos Memorial Library: Some 25 km (15 miles) north of Santa Cruz, just a short distance from the San Andreas fault, and over the Santa Cruz Mountains is the south bay town where there was considerable building failure. It is near the mountainous region where the greatest amount of housing collapses took place. There was no structural damage done to the town's public library. Two large plate glass windows shattered, and later the replacements were covered with a special film to inhibit shattering in the event they should break again. Two file cabinets fell over, one of which was damaged beyond repair. A third of the library collection of 125,000 volumes was thrown to the ground. Ten percent of books on the floor were found to be damaged. The shelving in the children's room was only about 2 meters high (54 inches) which may account for the fact that none of the shelving buckled or fell and damage was confined to fallen books. Shelving on the first floor failed completely and fell over like dominos. On the basement floor of the library, over three-fourths of the shelving was twisted and leaning. During the quake, a library staff member was caught in the windowless staff room. When the lights went out, she had to scramble over books in the dark in order to get to the stairwell. The next day someone thought she smelled smoke. It turned out to be this person's sandwich which had been put in the oven minutes before the quake. Librarians insisted they smelled "toast" but by that time it was cinders. Perhaps, most remarkably, an upright piano was thrown backward through a plate glass window of the library, landing on its back in a patio. The piano was in due course set upright and, although one key sticks, is reported to play better than ever.

West Valley College Library: Next door to Los Gatos in the city of Saratoga, this library was built in 1972 with shelving units not bolted to the floor because the facility manager at that time did not want to ruin the new carpet by punching it with holes. Also, shelving section frames were not welded together, top bracing was not extended to structural columns or walls, and sway braces were only clipped to the upright stack columns. Consequently, over ninety percent of the collection was dumped as the shelving ranges failed regardless of whether they ran east/west or north/south.

Saratoga City Public Library: This branch of the Santa Clara County Library System was the hardest hit of nine branches. Most of the collection was on the floor. All the adult non-fiction shelving had to be replaced. This meant boxing 100,000 books to wait for replacement shelves. The shelving was bolted to the floor and sway braced, but it twisted nonetheless. Some came off the wall. Books were hip deep in most aisles. Other damage included several shattered glass cases, broken light fixtures, split carpet, loosened fittings and a general mess. In Saratoga and all other County Library branches, it was the tall 2.133 m (84 inch) or 2.285 m (90 inch) shelving that twisted and bent. In most but not all cases, lower shelving was undamaged. Counter tops and shelf end panels also contributed to stability. The direction shelving ran did not make an appreciable difference, although more damage occurred in shelves that ran perpendicular to the fault.

Region B
(Libraries from 30 to 50 km of the epicenter)

Moss Landing Marine Laboratories of the California State University: One of the two libraries in this survey that are in condemned buildings, the MLML Library was part of a 1984 building overlooking the Monterey Bay of the Pacific Ocean. The earth beneath the building liquified during the quake. Shaking lasted approximately 30 seconds (twice as long as elsewhere) and was estimated to be the equivalent of a Richter Scale 8.0 (nearly an order of magnitude higher than the official 7.1). This resulted in the foundation moving quite actively in a westward direction, while the remainder either stayed in place or moved eastward. The building suffered major damage in the process and actually split in a couple of places but fortunately did remain standing. There were fifty people in the MLML building at the time, including four in the Library, but no one was hurt and virtually no equipment destroyed. The librarian was under her desk, while two students were under a table watching the floor separate by 30 cm (12 inches) from the wall right beside them and a fourth person was in the bookstack from which he later emerged white-faced but unharmed. Due to the settling of the building, all three exit doors jammed. Fortunately, one of the windows opened easily and the four were able to climb out, praying that a tsunami was not approaching.

The library collection was basically unharmed although twenty percent of the books fell to the floor from shelves which had been bolted to the floor, well braced, and wall shelving bolted to the walls. The free-standing shelves also ran in a north-south direction which the librarian had been told was the best way for shelving to run in their particular neighborhood of the San Andreas fault. While the California State University System proceeds with rebuilding the Marine Laboratories, temporary quarters were set up in the city of Salinas, and within two weeks part of the library was functioning, aided by the nearby availability of undamaged collections at the Hopkins Marine Station of Stanford University, the U.S. Naval Postgraduate School Library and the U.C. Santa Cruz library. This may be the only instance during the Loma Prieta earthquake where liquifaction contributed to the severity of library damage.

Gavilan College Library: Thirty percent of the books went to the floor. Located in the city of Gilroy east of the epicenter, the library books fell most commonly from shelves running north and south. The building received only some superficial cracks in plaster. Electric power and telephone service were out for twelve hours.

San Jose State University Library: This 1982 Clark Library building was built on hard soil and came through well. However, book shelving on the third, fourth and fifth floors twisted and was badly racked in various directions. There were no top braces or gussets and the sway bracing had been hooked rather than bolted or welded.

San Jose City College Library: There were no problems. Only five percent of the books fell and less of the audio-visual materials, because of better shelf arrangements.

San Jose Mercury-News Library: No damage at all to this newspaper library, only a power outage.

IBM - Almaden Research Library: In south San Jose, this relatively new library had no problem except for a few books that were dislodged.

San Jose Public Library: Here again, there was no structural damage to the main city library building but the shelving buckled and pulled away from the walls because of inadequate bracing. Both San Jose State University library and the San Jose Public Library were opened two weeks after the earthquake. Most regional libraries were open in a few days except where building repairs or stack structural correction was required.

Apple Computer, Inc.: Located in Cupertino, ten percent of the collection in this major library supporting research and development fell off the shelves even though all of the shelves run north and south. Audio-visual material had very little damage because it is kept in a locked cabinet and in closets. None of the collections were physically damaged and there were no water problems. Alarms went off but this was caused not by heat, smoke or dust but because people went running out of alarmed doors. The library was fully functional within four working days with the worst physical conditions having been partial height office walls or "landscape furniture" which fell because they were not properly braced. There were lots of stories in the library and adjacent laboratories of computers being dropped or dangling by cables although the data was still recoverable.

De Anza College Library: Also in Cupertino, sixty percent of the collections in this library fell to the floor. Half of these volumes were shaken off the shelves with the shelves remaining upright and intact. The other half were on 138 double-faced sections of freestanding, unbraced metal shelving that twisted and was so severely damaged that it was later removed from the building and replaced. All of the shelving involved ran in a north-south direction. Audio-visual materials suffered less, being housed on wall-mounted shelves recently installed and adequately braced. A book security system was damaged as were three computer terminals, a few television monitors, three lateral file cabinets, wooden bookshelves in one place, and an office chair damaged when shelving collapsed on it. While there were breaks in water lines on the roof of the building as the heating/air conditioning equipment moved around, the breaks did not result in any damage to the book collections. In the opinion of the College Librarian, the community college district administration moved too quickly to condemn the existing shelving even though some experts were convinced the shelving was salvageable.

City of Santa Clara Public Library: Because of foundation settlement in recent years, cracks existed in the walls and ceiling of the library addition. The tremor accelerated the condition thereby requiring pressure grouting of a crack in a shear wall. Electricity was out for forty-three hours and the telephone system failed. Three windows shattered, spewing glass shards over book ranges and seating areas as sixty percent (about 150,000 volumes) of the collection fell regardless of shelving direction. All of 180 full height metal free-standing shelving suffered extensive damage and had to be replaced two months later. Video cassettes were on low shelving, phonograph discs and compact discs in heavy bins and audio cassettes in wide cabinet drawers, each with no problem. The one patron who received facial cuts from falling books returned to the library two weeks later to chat with staff and view the damage. As he entered the building, a large aftershock of 5.5 caused everyone to dive under tables and counters, after which the staff suggested the patron consider using another library!

Santa Clara University Library: Shelving braces pulled loose and some shelving on uncarpeted floors moved 3.75 cm (1 1/2 inches). Under ten percent of the books in the main library were dislodged. All campus libraries reopened in two days. Yet, when one ugly plant fell over and lost all its dirt, staff were later sorry to find out it survived the earthquake as well as their long time efforts to kill it by neglect.

Research Library of ESL, Inc.: This library serves an electronic research and development firm in Sunnyvale, just a short distance north of De Anza College and Apple Computer. Ten percent of the collection was thrown to the floor, with north-south shelving affected much more than the east-west shelving. All audio-visual materials had been in enclosed cabinets and there was no damage. The ESL library bookshelves that were laterally braced across the top in the middle sections, but not at the ends, experienced powerful momentum such that the first and last double-face sections severely swayed during the quake. The basic library shelving had been reinforced about ten years ago with strut bracing running the full length of the room across the top of each stack range and made firm by wall bolting at two locations at the same end of the room. At the time of the quake, three engineers were seated next to a plate glass window near this shelving. They saw the stacks waving and swaying and trying to break loose toward them. All three engineers said later that they were frozen with fear and could not decide what to do so they just sat by the window and watched the movement of the shelving and the books being thrown to the floor in front of them. After the quake, it was discovered that one of the wall bolts had pulled out from the force of the stack movement. It had been held by a moly-bolt which had been inserted in wallboard instead of attached to structure. The second brace had fortunately gone into a vertical wood stud and held firmly, otherwise the entire row of ranges might have gone over like so many dominos and there could have been three badly injured persons, if not fatalities.

St. Joseph's College Library: This is the second library in this survey which was in a building that has been condemned. The college is located in Cupertino, by the foothills of the Santa Cruz Mountains and on the edge of this major south bay urban area. The library was located on the second floor of the main college building built in 1924. The building was, in part, unreinforced masonry structure, was severely fractured and had a tower which collapsed and killed a workman during the earthquake. Damage to the library itself would not have been so traumatic were it not complicated by the damage to the building as a whole and the inability to reach part of the library for cleanup. At least ninety percent of the college collections fell off the shelves. It did not make any difference which direction the shelving ran as the earthquake rolled and twisted the building. However, the librarian noted that metal stacks fell like dominos whereas some custom-built wooden shelving merely leaned to one side. Wooden shelving built into the walls retained more books than freestanding shelves, and shelves that were fully packed fared better than those with expansion room. Video tapes stacked on ordinary wooden shelving flew in all directions, but the shelving itself remained in perfect condition.

While there were no fire alarms that went off at the college library and no electrical problems or water problems, it was coincidence that books that had been wet as a result of an earthquake two months earlier were the only materials readily accessible. Those materials had been placed in a fish and poultry freezer until they could be placed inside a vacuum chamber for drying. (This was much the same process followed at the time that Stanford University's Meyer Library suffered a major construction-caused flood in 1978 and also for the Stanford Law Library's water soaked books a year later.) Perhaps one should not literally say there was no water damage; for, in fact, a fish tank in the library reference room had ruptured during the earthquake, spilling water that soaked the rug and caused mildew damage to books which fell on those areas of the carpeting. Part of the cleanup was to remove the dead fish littering the floor!

Although the building was condemned, staff were permitted to remove most of the books in due course. Staff rescued their African violets first. Then came video tapes because one could not walk into part of the library until they were picked up without the risk of smashing them completely. The final process was for the staff to rescue the cards from the shelflist, half of which covered the floor in the technical service processing office. To save time, since the cards were not in order, they were placed in large garbage bags for transport and brought to the new office for sorting. But the next morning, staff received a phone call from one of the maintenance personnel asking if librarians really wanted all those garbage bags discarded. He had put them in the trash dumpster - and fortunately had second thoughts.

Foothill College Library: About six percent of the collection fell in this library in Los Altos very near the San Andreas fault and northwest from the epicenter. The shelving for monographs runs east and west but did not experience any structural problems though it is on the mezzanine level and had no special bracing. Periodical bound volumes are on braced shelving running north and south from which one hundred percent fell. Though some water pipes broke in the ceiling, water damaged none of the collection.

Region C
(Libraries from 50 to 75 km of the epicenter)

Syntex Corporate Library: Located in the Stanford Research Park, this library came through in good shape with some books on the floor. As one official noted, "Buildings with a north-south axis seemed to be damaged less than those with an east-west axis. That's just the way the ground shook - this time." As in the case with Stanford University, shelving in the north-south axis seemed to dump fewer books and, as at Stanford, the worst collapse was shelving in the east-west axis. Syntex had the threat of water damage. Indeed, when all the ventilation systems were checked, more than a quarter of the rooftop fans that pump cool and hot air into the buildings were found to be damaged. They were mounted on a spring to protect them from the natural vibration of the building. Some of these large fans were torn off their mountings and were thrown as far as 90 cm (three feet), with all of the electrical wiring and duct work torn off as result. At Syntex the predominant sound was breaking glass.

William P. Wreden Books: Of the entire stock in the store in Palo Alto, only antiquarian materials on three sections of shelves fell because the sections had not been fastened to the wall. Two percent of the books were damaged when the shelf sections fell on top of them. Thus it was business as usual less than a week after the earthquake.

Menlo Park Public Library: Some twenty-five percent of the collection spilled onto the floors but none of the volumes were damaged. There were many fewer audio-visual materials that spilled because they were stored in bins and on lower shelves. The principal problem in the library was lack of stack bracing and bolting of the stacks to the floor, both in the 1957 and the 1968 wings. Despite an electric power outage for about twenty-four hours and many books on the floor, a surprising number of patrons wanted to stay and use the library.

United States Geological Survey Library: Though books were knee-deep in stack aisles, damage was minimal because the building in Menlo Park is single story on a concrete slab, stack ranges had top bracing extending wall to wall across every second section and sway bracing internal to sections was bolted rather than hooked. A dangerous condition existed where map cases were stacked up to twenty drawers high without drawer latches. The top four- or five-drawer units had all their drawers fly open. Many of these units had just been purchased and were not loaded with sheet maps, otherwise the weight of drawers running open might well have caused an imbalance and major damage could have resulted.

Redwood City Public Library: The main library occupies a 1988 structure of 3530 square meters (38,000 square feet) with a lobby dating from 1920, originally a firehouse. During construction, $400,000 had been spent to refill the creek bed with engineered soil on which the building rests. As a result, only fifteen percent of the books fell from the shelves and virtually none fell at two branch library buildings. Almost all the shelves run north to south in this case. Only two hundred volumes were damaged, mostly heavy art books.

Cañada College Library: Also in the west bay, and almost on the San Andreas fault in the western section of Redwood City, this library had fewer than a dozen volumes on the floor with no damage to materials, no water problems or electrical outages. The building is on bedrock.

Stanford University: As reported in the second section of this paper, the circumstances were varied. Some libraries had no problems at all except to pick up some books and others had severe problems. The latter group included the Graduate School of Business Jackson Library in a 1967 building that has required a good deal of structural reinforcement and the use of epoxy to fill many cracks. The library building will not be ready for full occupancy for some ten months after the quake, following which some new shelving must be put up to replace that badly damaged. The Food Research Institute Library shelving that collapsed was on the first floor and basement of an 1891 building in quarters that had been completely remodeled in the mid-1960's. Shelves that failed in the basement of the Law Library were in a reinforced concrete building built in 1975.

In the 1919 wing of the Stanford Green Library, there were over one hundred and fifty staff who immediately lost their work quarters. One month later, two-thirds were temporarily enabled to move back in since the badly fractured in-fill walls had been completely faced from floor to ceiling structure with plywood. About fifty staff will be in modular or trailer space for the next two to three years while the old wing is structurally reinforced and refinished at a cost which may reach $13,500,000.

In addition, the University has incurred or is currently undertaking earthquake-related library work that (excluding Law, Medical and Business library expenses) amounts to $500,000 in contract expenses, temporary space, repair of damaged bindings, shelf reading for proper classification order, replacement of damaged equipment, temporary bracing of shelving, replacement of certain shelving sections, plus adjustments in the new 1980 wing of Green Library in order to make temporary space accommodations for some of the staff who were displaced from the older wing. Similar stories could be related for any library in the Loma Prieta region where there was major building damage and especially in the two instances where the buildings were condemned.

San Juan Bautista City Library: This town sits directly on the San Andreas fault southeast of the epicenter. The only library event was one picture which fell and broke the glass. Not one book fell.

Hopkins Marine Station's Miller Library: There was a lot of noise there in Pacific Grove. The hanging light fixtures swayed. However the Library building, occupied in 1989, is on engineered fill soil, about 2 meters (7 feet) over bedrock. That fact together with the steel shelving having welded frames bolted to the floor, no sway or top braces but column gusset plates (similar to strap bracing from base to column), resulted in no damage and not one book on the floor.

Pacific Grove Public Library: Located almost due south of the epicenter by the ocean, one wing of the library shifted slightly, but this condition is not regarded as needing repair. Electric power was out for thirty-four hours. About at the same distance from the epicenter as Stanford University, none of the book collection fell and only a few collector's dolls fell in the children's area.

Region D
(Libraries from 75 to 110 km of the epicenter)

San Francisco State University Library: Built on sandy soil with high clay content, within 3 km (2 miles) of the ocean, the Leonard Library was constructed of reinforced concrete in three stages during 1952-1971. The seven floor library had about forty percent of its collection on the floor. Reportedly all of the shelving was "stressed in one way or another, from being wobbly in some instances to almost being on the floor in other instances." Asbestos was found escaping from a machine room on the sixth floor, so the top two floors were sealed off while that was taken care of.

Sutro Library of the California State Library: Located beside the San Francisco State University, this building had acoustic ceiling panels fall. Though it experienced no structural damage, a drip leak began in the fire-protection overhead sprinkler system.

California Academy of Sciences: Located a third of the way from the ocean to the San Francisco Bay, its libraries had shelving problems. Botany Library and Entomology Library shelving was damaged beyond repair. The Main Library stacks were damaged but could be repaired and strengthened.

Golden Gate University Library: This San Francisco building suffered structural damage to shear walls and supporting columns. Some stacks tilted and ten percent of collections fell. On the other hand, the Gleeson Library of the University of San Francisco had no damage except for one large window on the fourth floor which cracked.

San Francisco Public Library: Located much closer to the Bay, its worst condition was in the north wing of the main library where seven layers of closed stacks were pulled loose from the wall bolts and about one third of the 900,000 volumes housed in that section fell to the floor, especially from shelving running north and south. Less than one percent of the total collection bindings were damaged. Damage to the walls was not structural but there was a great deal of plaster broken, and glass and marble stack floors were split and shattered. Some sections of the library such as Art and Music had little or no damage. Three months later, and after some special staff projects were completed, the main library reopened for use.

The Book Club of California: The library and its offices and exhibit area are on the sixth floor of a building in downtown San Francisco. After the quake and as staff emerged from their places of protection, they found a few books toppled to the floor and all were undamaged including those in the exhibit cases. There was no damage to the club rooms or the two heavy free-standing glass display cases or the hand printing press. Not even a single bottle of wine had toppled in the storage area! As the staff descended five floors to the street, they saw that the stairways were lighted by the emergency lighting system and the building had sustained no obvious damage. Before the lease for the Book Club of California was last renewed, expensive seismic bracing and emergency systems were added to the building, creating a safer building although one with higher rent. An architect who is a member of the club had helped to assess alternative space for the club rooms. Some were turned down as structurally unsafe, or unsafe in the event of a fire. Once this particular building was improved, the club clearly made the right decision to stay in those quarters.

United States Environmental Protection Agency Library: Also in downtown San Francisco, four blocks from the Bay docks, the library was on an upper floor of a business block. Forty percent of the collection fell. However, the 200,000 microfiche and other audio-visual material had no problem due to their storage containers being either anchored, locked or on rolling carts. There was an immediate electrical failure. The librarian reached for a flashlight, saw fallen books and toppled map cabinets and strewn equipment, and headed for an exit. But that stairway had a burst pipe main and was flooding, so another had to be located. Electricity was out more than three days. There was no heat for some time, gas leaks being identified in the area. Curiously, the shelving company representative told the librarian that her shelving "did what it was supposed to do - unload the books. If the books had remained on the shelves they would have buckled."

Oakland Public Library: In these quarters on the east side of San Francisco Bay, fifteen percent of the books fell off the shelf. All branches had books down, but the main library suffered the most, especially in the closed stacks. The audio-visual materials suffered as much as did the books, with major amounts being on the floor. Yet only two dozen very heavy volumes were physically damaged. A water pipe broke in one branch, flooding the floor but there was little book damage.

A post-earthquake survey showed that the Oakland Public Library had several shelving problems. No freestanding shelves were bolted nor braced, although some wall shelves were. At a time when the main library shelving was moved some years ago, the braces were removed as not being safe. However, the replacement cost was so exhorbitant that the city Buildings Office would not finance the replacement and the library could not bear to pay from the book budget or with funds saved from staff vacancies.

As main library staff began to clear people from the building, some patrons were already back at work at the computer terminals searching and printing. Several people ran to the stacks to look for a special book. Those with books to take home insisted on checking them out. Some people objected loudly to the closure, insisting that the earthquake was over. Yet throughout the library system, bookcases fell in every library, dozens of them, all full of books. Some large, solid oak cases and some small narrow ones fell. Some were completely destroyed, splintered or bent. Some holding paperbacks were made of wire, round and lightweight, and they whirled around a few times before they went down. Some were old metal cases with sharp jagged corners that twisted and sagged. One massive case in the main library moved precisely 10 cm (4 inches) off its appointed place, without losing a book, just as though it had been lifted and moved by a crane. In a branch library next to the double-decked vehicular Cypress Freeway, one staff member stepped outside the library just in time to see the structure fall. Another staff member was going home to the north as the freeway fell just behind him and he saw the collapse in his rear view mirror. This branch library remained closed several days merely due to the heavy traffic congestion and emergency activity in the area.

Alameda County Law Libraries: The Main County Law Library in downtown Oakland had many fallen or broken shelves on the second floor and throughout the third floor. The librarian's desk was buried by three wooden bookcases with books, pictures and broken ceramic figures. The North County Branch also had comparable damage. However, the South County Branch in Hayward had less than 100 fallen books.

University of California at Berkeley: There was no significant damage in any campus library except some minor cracking and fallen plaster of walls in the Doe Library and three volumes which needed repair out of a total of one hundred off the shelves. The Biological Sciences Library had 200,000 volumes in a remote storage facility in Oakland in which twenty-two stack ranges fell over, spilling some 50,000 volumes of which 350 needed repair.

St. Mary's College of California: This 1968 college library in Moraga is just east of the Berkeley hills, not far from Oakland and Berkeley. Thirty-eight percent of the collection fell off the shelves, much more common on ranges running north and south toward the epicenter than from east to west. One hundred percent of the audio cassettes fell to the floor because the compartments in which they sit on top of shelves were not secured. However, only five percent of the video cassettes fell. Some three percent of the collection received damage to bindings ranging from minor to severe. Of the hanging light fixtures on the first floor, nine tenths broke loose and fell, leaving exposed wires. Consequently, maintenance personnel turned off electric power during the night although there was no loss of power on campus. Built on lakefill, the building rests on floating piles which worked well, as had been engineered. However, a design defect in the library was the lack of adequate shear-wall strength on the first floor. The first floor exterior walls had been largely glass between all the support columns, and the building lacked adequate strength to resist the forces of a quake of this magnitude. Wall fractures have now been partially resolved by filling in cracks with pressurized injections of epoxy resin. And during January of 1990, six shear walls were constructed between some of these exterior columns. Another problem was created by the hanging light fixtures each weighing 91 kg (200 pounds) which, having no safety chains, were not adequately secured. A third condition was created by the lack of bolted sway bracing in sections of the metal bookstacks. Miraculously, only one person was injured, a student, exiting the library through the front glass doors at the time the earthquake hit, whose wrist went through the glass.

The movement in the St. Mary's College library building was tremendous, with rocking, shaking and twisting. Even 150 km from the epicenter, some people were knocked to the floor. In addition to the roar, those in the building were in the midst of exploding glass, crashing light fixtures, collapsing shelves and falling books. The estimated 60,000 volumes that fell from the shelves came from a variety of conditions, some ranges of shelving appeared to move little while others completely collapsed or racked 45 degrees or more until they rested on wedged-in books. No stack range could be considered safe to work around until new bracing had been installed with welded frames. Computers and terminals came through unscathed.

The College Librarian and a professor of mathematical sciences were having a meeting in the Librarian's office at the time of the quake. When the rumbling started, both moved quickly to a central place in the building by the circulation desk. Later on, it was seen that the table in the Librarian's office where they had been talking had been absolutely crushed by a falling light fixture. Since the Librarian's office was surrounded by glass, as soon as the primary wave was over and they had moved to the circulation area, they were better prepared and safer for the more vigorous secondary wave to arrive. At that time, everything seemed to be happening in slow motion: lights seemed to be falling like leaves, the large window near the entrance turned opaque then it bowed and then collapsed. The whole room filled with white dust. Students were staggering around, then storming the front door. This professor helped the students leave in an orderly fashion and ran to cut the power, next going upstairs to look for injured people. At that point, he saw a decapitated head on the floor of the balcony in the library, first thinking it was some student's until realizing that it came from a statue!

Region E
(Libraries beyond 110 km from the epicenter)

Richmond is the location of the University of California Earthquake Engineering Research Center Library, a short distance from the northern part of San Francisco Bay. In this library, just one percent of the books fell off the shelves. The shelving itself was braced at the top but books were thought to have slid along individual shelves in a domino effect, the shelving going in a north-south direction. The fallen books were quickly re-shelved within two hours. Some heavy storage boxes fell from stack shelves with no apparent pattern. The only physical damage was that, after it rained several days later, minor damage was found in the roof which caused a leak along the edge of ceiling tiles by the end of a row of shelves.

At the time of the earthquake, the Librarian was in her office and an earthquake engineer was in the library. The engineer watched the clock, paused a moment and then stated: "That earthquake was around a 7 and was at least 50 km (30 miles) south of here." Other engineers in a meeting down the hall soon rushed in, noticed books on the floor and asked that library staff not move anything, so that they could take pictures the next day and make some observations about the pattern of fallen books - some fell from top shelves, some from middle and a few from bottom shelves.

This summary should not be finished without indicating how relatively fortunate Stanford University and indeed all Bay Area libraries were during the Loma Prieta Earthquake. Almost no collections were significantly damaged throughout the entire region. One can contrast that with the effects of Hurricane Hugo which hit the United States' South Carolina coast last September. The eye of the storm passed over the state about midnight on September 21st. The Charleston County Library suffered damage to eight of its eleven buildings. One branch library building was engulfed in a 2 meter (7-foot) water surge that swept materials off the shelves and mixed them in a mud bath with furniture and pieces of the roof which was penetrated by two oak trees. Another branch lost one-fifth of its entire collection due largely to a sewerage backup which rose to 46 cm (18 inches) within the library. Considering merely the library collections alone, I would rather live in an earthquake area and experience an occasional major one than to cope with the total loss of a major part of a collection and deal with the restoration of books which swam in sea water and mud.

Lessons Learned or Re-learned

In general it is prudent to plan in advance and be sure that library staff, including all new employees, are aware of emergency procedures. Staff should have the emergency manual accessible. Selected senior administrative staff, particularly those who live within a short distance of the library, should have a copy of the manual at home. The manual should include key phone numbers, lists of multiple commercial sources for supplies and emergency equipment and freezer capacity, and a list of the library emergency response team to deal with collection problems. The procedures should define emergencies, cover what should be done until help arrives, provide guidelines for handling emergencies of different scale, deal with water,fire, smoke, chemical, mud, sewage, mildew and other physical problems and may provide priorities for collection salvage.

A wise plan is to offer earthquake response instruction to all staff and to have annual brief update programs. A survey of emergency needs and skills can be useful in analyzing current vulnerability, inventorying in some detail the resources at hand, planning options for coping, and working out redundant resources or actions so as to plan good responses in a variety of types of emergency conditions.

One corporation in California conducts a survey to find out what kind of help each staff may need in the event of a major earthquake or other emergency and to identify the skills of staff who could contribute to the emergency recovery. Part of that survey is of personal office hazards, physical as well as chemical conditions. It includes questions of whether there are freestanding bookcases or storage or file cabinets above desk height which are not bolted or secured to the wall, terminal or computer type equipment not secured by an anti-skid pad, freestanding equipment above desk height mounted on casters, glass objects sitting on shelves or cabinets or files, plants or other heavy or hard or sharp-edged objects sitting on areas above desk height or hanging from ceiling, electrical appliances not normally stored in cabinet or desk, and other potential hazards. The survey also asks staff to volunteer information on their means of transportation to work, physical or mental conditions of one's family for which they would need special assistance or medication, any formal training as a paramedic, psychologist, nurse or as an engineer. These are but indicative of the kind of information that may be useful to supervisors in handling major emergencies, so long as the information is kept up-to-date and is available and accessible when it is needed.

A word to the wise is sufficient. So the Santa Clara County Library could, after October 17th, report: "Before the quake, library employees prepared for disaster by considering safety factors, recommending safe furniture placement, securing heavy items, attending emergency preparedness classes, and especially by defining a clear vision of their roles. That worked well for us. The training included first aid as well as coping with gas and electrical problems. I also believe that the ability of staff to make sound independent decisions was a crucial success factor. Staff are used to coping with problems like medical emergencies, children left without parents, overflowing plumbing, etc. These experiences gave them the cool heads which were so necessary."

Techniques for housing library collections present a quandary in trading off between safety of collections and ease of use. Thus, except for extreme rarities or the most precious manuscript materials or for certain formats including maps, microfiche, slides, and posters, open shelving will continue to be the norm. Shelving must, however, be braced adequately. Internal longitudinal strengthening by use of spreaders or back panels between columns, and top and end bracing, as well as bolting to the floor, are routine (or should be) in areas which may experience major quakes. Gussets or other lateral strengthening of the column are necessary in traditional library steel shelving that is cantilevered off the floor (in terms of resisting seismic forces). Sway bracing of cantilevered bracket-type steel shelving (bracing generally occurring in every fourth or fifth section in a range) should be bolted and never merely hooked. And, if sway bracing is used, two X's, one above the other so as to treat the lower half separate from the upper half, is preferable for full-height shelving. (See the Appendix for comment on safe design of library shelving to withstand earthquake forces.)

In Bay Bridge Books in Oakland, a city where many library books were shaken off their shelves, the shelves in this shop for newly published books all tilt somewhat backward and not a single book came off the shelves during this earthquake. Although this store was some 80 km (50 miles) from the epicenter, the quake result suggests that a big help may come from a small amount of backward tilt, similar to the shelf slope in most bookmobiles. Base-isolation techniques which work beneficially on buildings of modest height can also be helpful for shelving, as demonstrated in compact shelving facilities where the ranges are on movable carriages. Keeping books back instead of aligned to the front edge of the shelf may be marginally beneficial. Friction on shelf surfaces would also be a restraint in modest quakes, e.g. a felt or other slightly abrasive material.

In private offices, it may be possible to have shelves behind sliding doors that would protect materials much better than swinging doors with magnetic catches. One can use wire or cord retainer lines, bungee cords (elastic straps) or guard rails (fixed or moveable) across the face of the shelf if it is felt that any potential damage to the books must be prevented or that an individual sitting in front of the shelves feels endangered were books to be thrown off the shelves. This technique has been used for the storage of fragile items such as chemical stores or the storage of phonograph discs.

Though the Loma Prieta experience shows that shelving running away from the epicenter and in line with the historical direction of slippage will not disgorge books as much as those running perpendicular, this information is of little help. Planned or calculated directional shelving failure or book disgorging is seldom feasible. Stanford's random stack failure patterns support that view as do extensive Japanese studies of the post-earthquake multi-directional falling of tombstones in cemeteries.There is even less predictability as to the epicenter loci for the next century than there is for which fault will fracture. Major fractures do not cluster in a small region along a fault.

If a library is very closely located to a fault line, one could possibly conclude that the fracture will be toward one direction or the other along the fault and most shelving should go in that direction. But all shelving in such a building should be engineered appropriately without gambling on epicenter directional wave source.

One thought though; if fifty percent of the shelving is perpendicular to the nearest fault and the balance parallel, it may be that during any single event, at least some of the shelving should fare better than might be the case with all shelving running the same direction.

Equipment should be bolted to structural elements within the wall, not to a drywall or plasterboard surface, but to something more rigid. Just as one should anchor a grandfather clock to a wall stud, so should any heavy equipment more than 1 metre (30 inches) tall be bolted or very heavily tethered. Since most staff work areas are used much less than half time, it would be prudent to leave file drawers latched or locked so that they will not run open and possibly drop their contents. Stacked units of drawers for sheet maps or architectural drawings should be affixed one to another and the drawers equipped with locks or latches. Placing non-skid mats under some equipment and bolting down or tethering valuable equipment placed on counters and desks will reduce damage.

No books or boxes of library materials should be on the floor or on top of tall cabinets. Such material should at least be placed on platforms or something similar to guard against modest water flooding. Nothing heavy such as vases or small metal equipment should be placed on top of shelves. Common in-building injuries derive from falling equipment or objects falling off the wall or from parts of light fixtures or ceilings. Such occurrences are why people are taught to immediately get under a desk or heavy table or stand in a doorway away from glass.

Electronic paging devices may be of major help if the local phone system is out of order. Battery-powered radios help assure receipt of emergency information. Emergency electric power is necessary for persons who are exiting buildings after the normal power fails. Flashlights should be at hand, especially if the building does not have an emergency light system. Electric surge protectors are necessary for computer equipment. Lots of plastic sheeting should be available to provide book protection in the case of water leaks or rain coming through broken windows or damaged roofs. (The rain held off for three days after the Loma Prieta quake.) Fire which can follow an earthquake can be devastating, as the 1906 San Francisco quake showed and as we were reminded by the San Francisco Marina District experience after Loma Prieta. And one could continue in a similar vein with listing of many actions of common sense to reduce hazards and reduce the clean-up chore. In any event, the wise advice is to consider seriously the local situation, plan ahead and invest in the safety of people and library collections.

Attention to building codes and heeding the advice of structural engineers are obvious points. In the past decade or so, the science of earthquake engineering has moved from infancy well along toward theoretical completeness. Guarding against an earthquake of any magnitude is now possible, though it is a question of money and time and putting current engineering knowledge into practice. Spectral analysis has enabled engineers to decipher an earthquake's distinctive signals into constituent parts. Knowing what soil conditions exist, engineers can now design buildings accordingly.

Structural engineers seem to be moving toward the principle of siting buildings on a massive base which rides with the movement of the ground but which is isolated from the upper body. This base-isolation technique allows moderate height buildings to float on a cushion of rubber and steel pads and thus, instead of strengthening structures to resist ground motion, base isolation works to break the connection between the building and the ground. The sandwich of rubber and steel between the structure and its foundation may be replaced by chrome and steel sliders for the less elastic pads. After viewing the first U.S. project built on isolators in 1985, the use of base-isolation in Japan is said to be very popular, with thirty-eight base-isolated buildings either completed or under construction in Japan and dozens more on the drawing board. Base-isolation typically adds from one to five percent to a new building's cost. And the technique is not useful for more than fifteen stories and is unsuitable for use on very soft soils. Compact shelving installations demonstrate that base-isolation principles also apply to equipment. These comments are merely to suggest how advanced is the development of engineering techniques to safeguard buildings and their occupants.

In California, a financial question exists of whether a library can afford to build to the requirements established by the *Los Angeles Building Code* Division 88 which is for life safety purposes, or whether the library can afford to meet the much more rigorous *Uniform Building Code* issued by the International Conference of Building Officials which will safeguard the structure itself as well as occupants. Stanford University at present gives prime emphasis to applying the Division 88 Code. New buildings should meet as rigorous a code as is reasonable and older buildings should be given particular attention for strengthening.Unreinforced masonry buildings, as an example, are demonstrably vulnerable in moderate earthquakes, and thus this particular structural type is a particularly important target in the continuing effort to adapt older buildings to the requirements of seismic resistance.

It would give librarians and others a good deal of solace if earth scientists could predict the place, time and magnitude of major earthquakes. Comprehensive research on earthquake prediction has been underway in Japan since 1964, the year of the destructive Niigata earthquake. The most famous prediction took place in 1975 in northeastern China. In the city of Haicheng there were sudden rises in well water levels and a dramatic increase in the number of small earthquakes. Just five and one half hours after the public warning, an earthquake of 7.3 magnitude severely damaged this city of 100,000 people with hundreds of buildings and factories destroyed, but only a small number of deaths resulted. There are some instances where unusual behavior on the part of creatures (fish, reptiles, rodents, horses and house pets) is thought to be a precursor. In 1969 in China, a large city zoo observed that a tiger was depressed, pandas screamed, yaks did not eat, turtles were restless, and swans stayed away from the water. Within just a few hours, there was a 7.4 earthquake. Serious predictive research continues to be done on crustal movement, seismic gaps, ground water, tremor patterning, foreshocks, geoelectricity and geomagnetism. Studies of magnetic anomalies using tilt meters and other applied techniques have produced mixed results.

While it is not clear what may be the scientific implications, two Stanford University engineers detected very unusual electro-magnetic waves in the weeks and hours before the October 17th Loma Prieta earthquake. Sensors monitoring ultra-low frequency (0.012 to 10 hertz) background noise began to detect a substantial increase as early as twelve days before the tremor. And in some of the higher frequencies, this noise dropped off to a surprising degree the day before the earthquake. (In the past, researchers from Japan and the Soviet Union have reported radio waves preceeding large earthquakes, waves in the 10 hertz to 32 kilohertz range.) Starting three hours before the earthquake, the Stanford equipment recorded a huge increase in the lowest frequency range, so large that the instruments issued warnings that the data were off the scale.

Until there is a proven methodology for predicting time, place and rough magnitude, it is merely interesting to speculate about how we, with responsibility for our library patrons and collections, would plan, and how we would respond if, in fact, we had several hours or a day of warning before a major earthquake. But the physical origin of false alarms is a reality today, and may ever be. Even if scientists find a dependable method, librarians and other officials must plan for earthquakes in historically active parts of the world - doing at least as well as officials in California. Hopefully doing much better.

Appendix

Example of Library Shelving Specification

Though book shelving had failed before, no doubt many times and places, the public and academic libraries in the October 1987 Whittier California earthquake demonstrated the need for proper design and installation of book stacks to cope with dynamic geology. The State of California manual cited in the "Selected Bibliography" as *Seismic Safety Standards* provides design criteria, specifications and drawings of standard details and installation instructions. The manual covers wooden and metal shelving and moveable compact shelving installed on carriages. It covers rigidly supported shelves as well as flexibily supported cantilevered freestanding shelves. The manual specifies design practices to minimize the potential for injury of people from library shelving during an earthquake and maximize the protection of property.

In 1976, Stanford University sought an installation of metal bookstacks which were to be floor-supported, single-tier units, double and single faced with cantilevered bracket-type shelves. No overhead bracing was allowed, nor was bracing to building structure between ranges, nor was diagonal sway bracing (x-bracing) because for research library collections the reduction in shelf depth was not acceptable. An extract from the specifications for this Cecil H. Green Library follows:

C. Performance Criteria:

1) Floor anchored stacks: Each stack section shall be anchored to a 6" (minimum) structural reinforced concrete slab with drilled or pre-set anchors. Each stack section shall be anchored at the ends of the base at each upright. Anchors shall be not less than 3/8" in diameter and have a minimum embedment of 3 inches. The General Contractor shall coordinate his work with the shelving manufacturer and supplier such that the spacing and

location of reinforcing and other embedded items will not interfere with the placing of anchors. No reinforcing steel shall be cut. N.I.C. carpeting in stack areas shall not be allowed to run under stack bases.

4) The entire system, including columns, bases, all connections and anchorages shall be capable of resisting a lateral seismic force, Fp = 0.25 Wp, in any direction, with a maximum lateral deflection of 5/8 inch at the top of the shelving, within the allowable working stresses permitted by the 1976 U.B.C. Wp is defined as "the total weight of the shelving system plus 50 p.s.f. of shelving to account for book storage." Stresses and deflections shall be investigated for the following conditions:

a. The shelves fully loaded in combination with seismic forces.

b. The shelves loaded one side of center posts in combination with seismic forces.c. The shelves loaded one side of center posts. Lateral deflection at the top of the shelving shall not exceed 3/8 inch.

5) For stability and to minimize longitudinal and transverse displacements, gusset plates at the base of the stack columns may be used. These gussets shall not extend beyond the shelf base and shall be concealed within.

7) Shelf Loading: Shelving shall have a design load of 50 pounds per square foot and temporary deflection not to exceed 3/16 inch with no permanent deflection.

2.01 Products-Materials

A. Sheet Steel ASTM A 366, cold-rolled sheet.

1) Provide full finished, stretcher leveled sheet of quality known commercially as "furniture stock" for shelves and end panels.

B. Fasteners: Cadmium-plated steel, manufacturer's standard types and sizes.

C. Sheet Steel Finish: Manufacturer's standard baked enamel finish; consisting of cleaning, phosphatizing process and alkyd enamel coating baked for 30 minutes at 285 degrees F., to provide minimum of 1.0 mil thick dry film thickness.

1) Provide coating with abrasion coefficient of 25 liters per mil, ASTM D 968.

2.02 Fabrication

D. Standard Unit Sizes: Except as otherwise indicated, provide units of 24" and 36" nominal widths, with shelf width and unit height as follows:

1) Bracketed Shelf Width: Nominal 10", newspaper shelves: nominal 18".

2) Base Shelf and Base: Nominal 12" typical, newspaper base shelf at 18".

3) Overall Height: 90" typical with 42" reference/bibliography in locations as indicated and 66" at reference desk.

E. Upright Posts: Manufacturer's standard tubular or back-to-back channel design; size, gauge, and reinforcement as needed for loading, but not less than 16 gauge. Provide base shoe with resilient pad of rubber or neoprene, except where base brackets or other components transmit loading to floor. Provide for electrical wiring as indicated.

F. Bottom Spreaders: 18 gauge minimum, 16 gauge if welded. Where structurally possible, manufacturer should locate bottom spreaders so as not to obstruct depth of double faced stack units.

G. Top Tie Channels: 18 gauge minimum, 16 gauge if welded.

1) Weld bottom spreaders and top tie channels to upright posts if necessary for the elimination of sway bracing on free-standing ranges (bracing not permitted).

H. Base Brackets: 16 gauge minimum for flanged construction; 11 gauge minimum for plate-type construction; 10" high x full width of base shelf; top and front edges rounded and flared to match shelf brackets. Provide adjustable leveling device at each end of bracket, with shoe and resilient pad of rubber or neoprene, located for concealment under base shelf and behind end panel.

I. Base Shelf and Base: 19 gauge minimum, manufacturer's standard closed-base construction.

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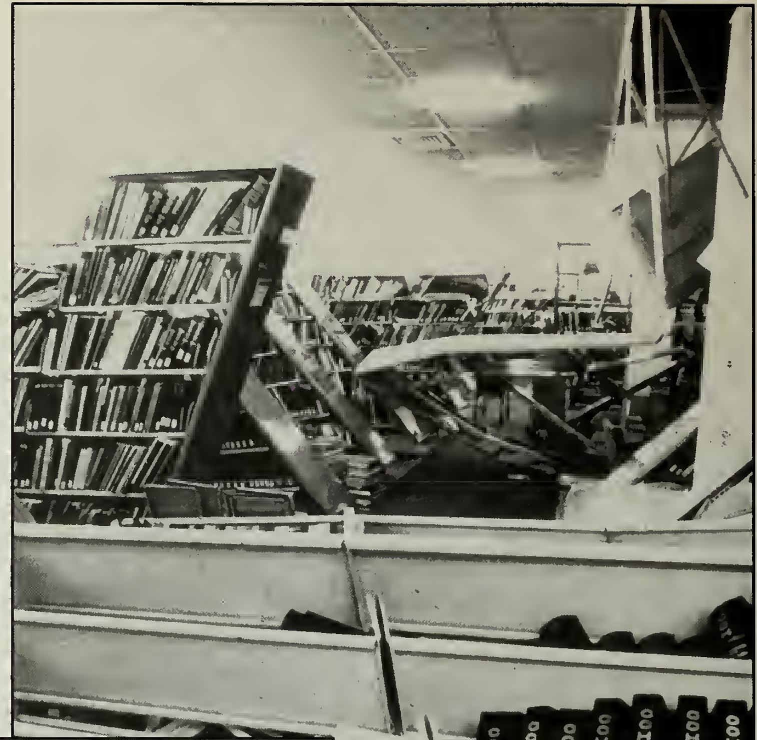
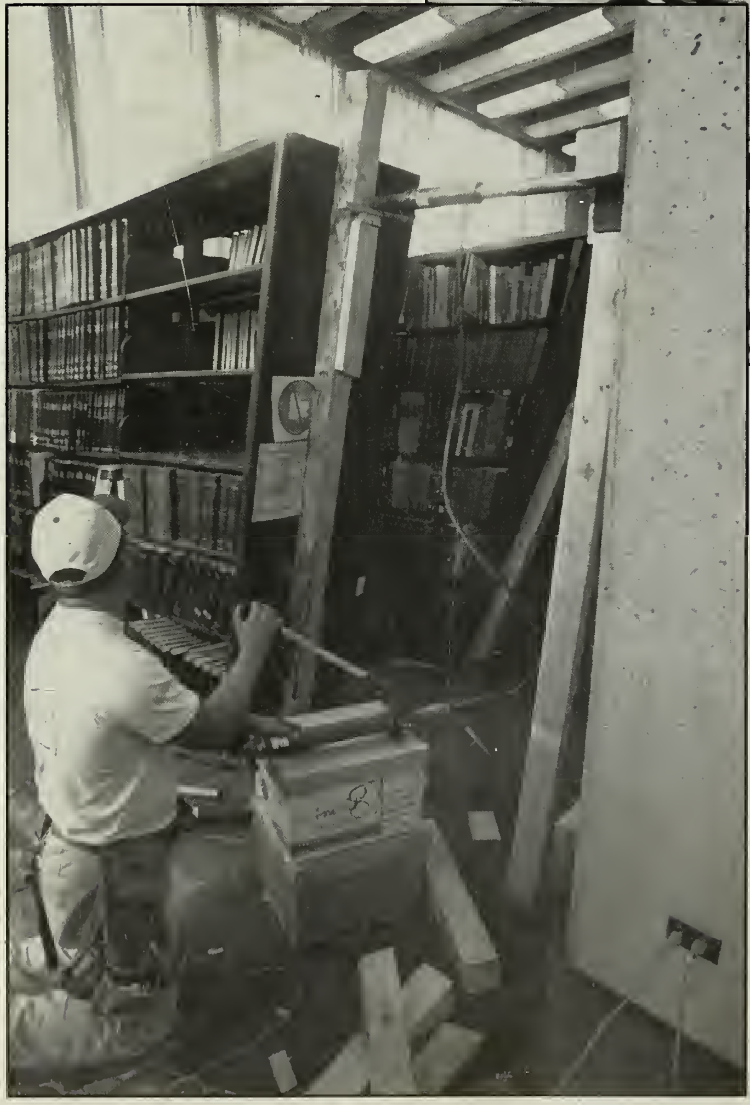


Shelving fallen in different directions and fallen ceiling tile and frames. (J. Hugh Jackson Library, Stanford University)



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